(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 855 597 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
29.07.1998 Bulletin 1998/31

(51) Int. Cl.[6]: **G01P 21/02**, G01P 3/56, G01P 3/00, B60C 23/06

(21) Application number: **98101381.6**

(22) Date of filing: **27.01.1998**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **27.01.1997 JP 12748/97**

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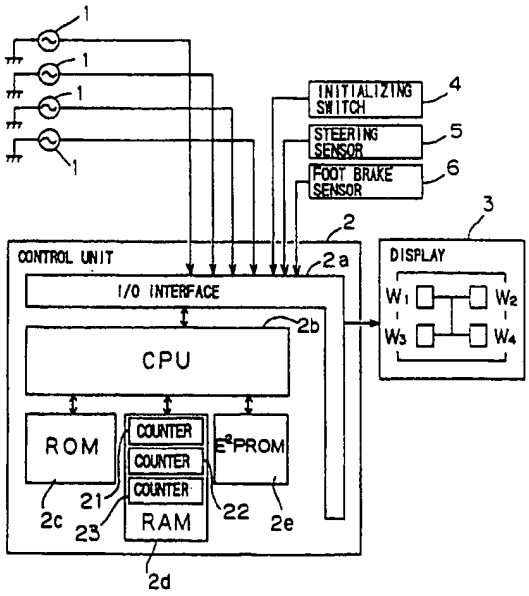
(54) Device for determining initial correction factors for correcting rotational angular velocity measurements of vehicle tires

(57) A device for operating correction factors for correcting outputs of rotational angular velocity detectors (1) for detecting the rotational angular velocities of four tires mounted on a vehicle. The device judges whether or not the vehicle is linearly traveling. If the vehicle is linearly traveling, an initial correction factor K_1 for eliminating the effect of a difference in effective rolling radius between the right and left front tires and an initial correction factor K_2 for eliminating the effect of a difference in effective rolling radius between the right and left rear tires are calculated on the basis of the outputs of the rotational angular velocity detectors (1). When it is judged that the vehicle is linearly coasting, an initial correction factor K_3 for eliminating the effect of a difference in effective rolling radius between the front tire and the rear tire is calculated.

Alternatively, when it is judged that the vehicle is cornering, an initial correction factor X_3 is calculated, taking account of slip factor R_5, a judged value D for judging a drop in air pressure of the tire, and a lateral acceleration LA of the vehicle.

If K_3 is calculated in both alternative ways, means may be provided to determine and select the candidate correction factor having the higher precision.

FIG. 2



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Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an initial correction factor operating device used for a tire pressure drop detecting device, for example, for finding an initial correction factor for eliminating the effect on the rotational angular velocities of the tires by a difference in effective rolling radius depending on an initial difference between tires.

Description of Related Art

In recent years, as a safety device of a four-wheel vehicle such as an automobile or a truck, devices for detecting the drop in air pressure of a tire (DWS) have been developed, and some of them have been put to practical use.

An example of a method of detecting the drop in air pressure of a tire is a method utilizing a difference among the respective rotational angular velocities F_1, F_2, F_3, and F_4 of four tires W_1, W_2, W_3, and W_4 mounted on a vehicle. This method utilizes the fact that the rotational angular velocity F_i ($i = 1, 2, 3, 4$) changes depending on the condition of the air pressure of the tire W_i. That is, when the air pressure of any one of the tires W_i drops, the effective rolling radius of the tire W_i decreases. As a result, the rotational angular velocity F_i of the tire W_i increases. Therefore, the drop in the air pressure of the tire W_i can be judged on the basis of the difference in the rotational angular velocity F_i.

The effective rolling radius is a value obtained by dividing the travel distance of the tire W_i in one free rotation in a loaded state by 2π.

A judged value used in detecting the drop in the air pressure of the tire W_i on the basis of the difference in the rotational angular velocity F_i is found by the following equation (1), for example (see Japanese Patent Laid-Open (KOKAI) No. 305011/1988, Japanese Patent Laid-Open (KOKAI) No. 212609/1992, etc.).

$$D = \frac{\frac{F_1 + F_4}{2} - \frac{F_2 + F_3}{2}}{\frac{F_1 + F_2 + F_3 + F_4}{4}} \times 100 \quad (1).$$

If all the effective rolling radii of the tires W_i are the same, the respective rotational angular velocities F_i are the same ($F_1 = F_2 = F_3 = F_4$). In this case, the judged value D is zero. Therefore, thresholds D_{TH1} and D_{TH2} (where D_{TH1}, $D_{TH2} > 0$) are set. When the condition indicated by the following expression (2) is satisfied, it is judged that there is a tire W_i whose air pressure drops. When the condition is not satisfied, it is judged that all the tires W_i have normal internal pressure.

$$D < -D_{TH1} \text{ or } D > D_{TH2} \quad (2).$$

The effective rolling radius of actual tires varies within a fabrication tolerance (such variation is referred to as an "an initial difference" hereinafter). That is, even if all the four tires W_i have normal internal pressure, the effective rolling radii of the four tires W_i differ due to the initial difference. Correspondingly, the rotational angular velocities F_i of the tires W_i vary. As a result, the judged value D may be a value other than zero. Therefore, it may be erroneously detected that the air pressure drops, although it does not drop. In order to detect the drop in the air pressure with high precision, therefore, it is necessary to eliminate the effect of the initial difference from the detected rotational angular velocity F_i.

SUMMARY OF THE INVENTION

It may be considered that as a technique for eliminating the effect of an initial difference from rotational angular velocities F_i, a technique proposed in Japanese Patent Application Serial No. 8-58039 (not published as of the filing data of the present application) is applied. In the technique, initial correction factors K_1, K_2, and K_3 are calculated as expressed by the following equations (3) to (5):

$$K_1 = F_1 / F_2 \quad (3)$$

$$K_2 = F_3 / F_4 \quad (4)$$

$$K3 = \frac{F_1 + K_1 \times F_2}{F_3 + K_2 \times F_4} \quad (5).$$

The initial correction factor K_1 is a factor for correcting a difference in effective rolling radius depending on an initial difference between right and left front tires W_1 and W_2. The initial correction factor K_2 is a factor for correcting a difference in effective rolling radius depending on an initial difference between right and left rear tires W_3 and W_4. The initial correction factor K_3 is a factor for correcting a difference in effective rolling radius depending on an initial difference between the front tire W_1 and the rear tire W_3.

The rotational angular velocities F_i are corrected as expressed by the following equations (6) to (9) using the calculated initial correction factors K_1 to K_3, so that new rotational angular velocities $F1_i$ are found. Consequently, the effect of the initial difference on the rotational angular velocities F_i is eliminated:

$$F1_1 = F_1 \quad (6)$$

$$F1_2 = K_1 \times F_2 \quad (7)$$

$$F1_3 = K_3 \times F_3 \quad (8)$$

$$F1_4 = K_2 \times K_3 \times F_4 \quad (9).$$

When the initial correction factors K_1 to K_3 are calculated, the vehicle must be linearly coasting. That is, if the vehicle is linearly coasting, the effect of the slip factor of the tire hardly affects the rotational angular velocity F_i. As a result, the initial correction factors K_1 to K_3 faithfully representing a difference in effective rolling radius depending on the initial difference can be obtained. Particularly, the initial correction factor K_3 is found on the basis of the ratio of the rotational angular velocities of the front tire and the rear tire, whereby the effect of the slip factor of the driving tire must be reliably eliminated upon setting driving torque or braking torque to approximately zero. In order to obtain the initial correction factor faithfully representing a difference in effective rolling radius depending on the initial difference, it is essential that the vehicle is caused to linearly coast.

On the other hand, the tire pressure drop detecting device according to the above-mentioned proposed technique does not comprise means for automatically detecting that a vehicle is linearly coasting. In the tire pressure drop detecting device according to the proposed technique, therefore, the calculation of the initial correction factors K_1 to K_3 is started in response to an operation of an initializing switch by a user. That is, when the initial correction factors K_1 to K_3 are calculated, the user operates the initializing switch upon intentionally causing the vehicle to linearly coast. Consequently, the device is informed that the vehicle is linearly coasting.

A public road is generally considered to be a road on which the vehicle is caused to linearly coast. In view of present road environments such as chronic traffic jam and a small number of straight roads, it is difficult and it is not preferable from the point of view of traffic safety to intentionally cause the vehicle to linearly coast on the public road. Therefore, a technique that can easily find a correct initial correction factor has been desired.

An object of the present invention is to provide an initial correction factor operating device capable of simply finding a correct initial correction factor.

Another object of the present invention is to provide a device capable of finding a correct initial correction factor even if a user does not give special attention to the calculation of the initial correction factor.

A device according to the present invention comprises means for judging whether or not a vehicle is linearly traveling, and means for calculating an initial correction factor K_1 for eliminating the effect of a difference in effective rolling radius depending on an initial difference between right and left front tires on rotational angular velocities of the tires and an initial correction factor K_2 for eliminating the effect of a difference in effective rolling radius depending on an initial difference between right and left rear tires on the rotational angular velocities of the tires on the basis of an output of the rotational angular velocity detecting means, on condition that it is judged that the vehicle is linearly traveling.

When the vehicle is traveling on a public road, the vehicle will be temporarily linearly traveling, although it is not coasting, or linearly coasting.

The device according to the present invention is so adapted in view of the foregoing point as to judge whether or not the vehicle is linearly traveling, and calculate, when the vehicle is linearly traveling, the initial correction factors K_1 and K_2 even if the vehicle is not coasting. Consequently, it is possible to simply calculate correct initial correction factors even if a user does not intentionally cause the vehicle to linearly travel.

The device according to one embodiment of the present invention further comprises means for judging whether or not the vehicle is coasting, and means for calculating an initial correction factor K_3 for eliminating the effect of a difference in effective rolling radius depending on an initial difference between the front tire and the rear tire on the rotational

angular velocities of the tires on the basis of the calculated initial correction factors K_1 and K_2 and the output of the rotational angular velocity detecting means, on condition that it is judged that the vehicle is linearly traveling and it is also judged that the vehicle is coasting.

Consequently, the initial correction factors K_1 to K_3 are calculated upon automatically detecting that the vehicle is linearly coasting. Consequently, the user need not intentionally cause the vehicle to linearly coast, so that it is possible to easily calculate a correct initial correction factor.

The device according to one embodiment of the present invention further comprises means for judging whether or not the vehicle is cornering, means for finding the slip factor Rs of the tire, and means for calculating an initial correction factor K_3 for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means, the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined operation expression when it is judged that the vehicle is cornering.

The device may further comprise means for calculating a judged value D for judging the drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means. In this case, it is preferable that the means for finding the slip factor Rs substitutes the lateral acceleration LA of the vehicle and the judged value D into a predetermined operation expression, to find the slip factor Rs of the tire.

The device according to one embodiment of the present invention further comprises means for calculating the lateral acceleration LA of the vehicle on the basis of the output of the rotational angular velocity detecting means, means for calculating a judged value D for judging the drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means, means for substituting the lateral acceleration LA of the vehicle and the judged value D thus calculated into a predetermined first operation expression, to find the slip factor Rs of the tire, and means for calculating an initial correction factor K_3 for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means, the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined second operation expression, on condition that it is judged that the vehicle is cornering.

The initial correction factors K_1 to K_3 are used for the purpose of eliminating the effect of the initial difference from the rotational angular velocities F_1, F_2, F_3 and F_4 of the respective tires in finding the judged value D for judging the drop in air pressure of the tire, for example. On the other hand, the rotational angular velocities F_1 to F_4 also vary depending on the movement of the load on the vehicle at the time of cornering. In finding the judged value D, therefore, the variations in the rotational angular velocities F_1 to F_4 due to the movement of the load on the vehicle is preferrably corrected. An equation used for the correction is the following equation (10), for example. In the following equation (10), A1 and A2 are constants:

$$D' = D - (A1 \times LA + A2 \times LA \times Rs) \quad (10).$$

The slip factor Rs corresponds to the ratio of the rotational angular velocity of the driving tire to the rotational angular velocity of the following tire, so that it can be expressed by the following equation (11) in the case of an FF (front engine front drive) vehicle, for example:

$$Rs = \frac{F_1 + K_1 \times F_2}{K_3 \times F_3 + K_2 \times K_3 \times F_4} - 1 \quad (11).$$

On the other hand, the initial correction factors K_1 to K_3 are generally calculated when all the four tires have normal internal pressure, for example, after the tires are replaced. If the initial correction factors K_1 to K_3 are accurately determined, therefore, a judged value D' should be zero during cornering. If zero is substituted into D' in the foregoing equation (10), solving the equation for the slip factor Rs, therefore, gives the following equation (12). The equation (12) corresponds to a first operation expression.

$$Rs = \frac{D - A1 \times LA}{A2 \times LA} \quad (12).$$

The slip factor Rs can be thus calculated on the basis of the lateral acceleration LA of the vehicle and the judged value D.

When the slip factor Rs expressed by the equation (12) is substituted into the foregoing equation (11), to arrange the equation with respect to K_3, the following equation (13) is obtained. The equation (13) corresponds to a second

operation expression.

$$K_3 = \frac{1}{Rs+1} \times \frac{F_1 + K_1 \times F_2}{F_3 + K_2 \times F_4} \quad (13).$$

The initial correction factor K_3 can be thus calculated on the basis of the initial correction factors K_1 and K_2, the slip factor Rs, and the rotational angular velocities F_1 to F_4.

The equation (13) for calculating the initial correction factor K_3 is derived from an equation for eliminating the movement of the load on the vehicle at the time of cornering from the rotational angular velocity F_i. When the vehicle is cornering, therefore, a precise initial correction factor K_3 can be calculated. Even if the vehicle is not linearly coasting at the time of usual traveling, for example, the precise initial correction factor K_3 can be calculated if the vehicle is only cornering.

When the vehicle is cornering, an error may be included in the initial correction factor K_3 depending on the value of the slip factor Rs. If the device further comprises means for judging whether or not the slip factor Rs takes a value within a predetermined range, and means for inhibiting the calculation of the initial correction factor K_3 when it is judged that the slip factor Rs is in the range, it is possible to prevent the initial correction factor K_3 from being erroneously calculated.

The device according to one embodiment of the present invention further comprises means for judging whether or not the vehicle is coasting, means for calculating an initial correction factor Kx for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires on the basis of the calculated initial correction factors K_1 and K_2 and the output of the rotational angular velocity detecting means on condition that it is judged that the vehicle is linearly traveling and it is also judged that the vehicle is coasting, means for judging whether or not the vehicle is cornering, means for calculating the slip factor Rs of the tire, means for calculating an initial correction factor Ky for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means, the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined operation expression on condition that it is judged that the vehicle is cornering, means for judging which of the calculated initial correction factors Kx and Ky is higher in precision, and means for taking the initial correction factor which is judged to be higher in precision as the final initial correction factor K_3 for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires.

The device may further comprise means for calculating a judged value D for judging the drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means. In the case, it is preferable that the means for finding the slip factor Rs is one for substituting the lateral acceleration LA of the vehicle and the calculated judged value D into a predetermined operation expression, to find the slip factor Rs of the tire.

The device according to one embodiment of the present invention further comprise means for judging whether or not the vehicle is coasting, means for calculating an initial correction factor Kx for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires on the basis of the calculated initial correction factors K_1 and K_2 and the output of the rotational angular velocity detecting means on condition that it is judged that the vehicle is linearly traveling and it is also judged that the vehicle is coasting, means for calculating the lateral acceleration LA of the vehicle on the basis of the output of the rotational angular velocity detecting means, means for calculating a judged value D for judging the drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means, means for substituting the lateral acceleration LA of the vehicle and the judged value D thus calculated into a predetermined first operation expression, to calculate the slip factor Rs of the tire, means for judging whether or not the vehicle is cornering on the basis of the calculated lateral acceleration LA of the vehicle, means for calculating an initial correction factor Ky for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means, the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined second operation expression on condition that it is judged that the vehicle is cornering, means for judging which of the calculated initial correction factors Kx and Ky is higher in precision, and means for taking the initial correction factor which is higher in precision as the final initial correction factor K_3 for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires.

According to the above-mentioned construction, the initial correction factor Kx calculated in a case where the vehicle is linearly coasting and the initial correction factor Ky calculated in a case where the vehicle is cornering are compared to judge which of the initial correction factors is higher in precision. The initial correction factor which is higher in

precision is taken as the final initial correction factor K_3. Consequently, a more precise initial correction factor K_3 can be obtained, as compared with that in a case where an initial correction factor K_3 is calculated by limiting either one of the cases.

Also in this case, it is preferable that the calculation of the initial correction factor K_3 is inhibited when the slip factor Rs is in a predetermined range.

In the device according to one embodiment of the present invention, the means for calculating the initial correction factor Kx includes means for subjecting a plurality of data to an average operation, and the means for calculating the initial correction factor Ky includes means for subjecting a plurality of data to an average operation. The means for judging which of the initial correction factors Kx and Ky is higher in precision includes means for judging the precision on the basis of the numbers of data which have been subjected to the respective average operations.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic block diagram showing the construction of a tire pressure drop detecting device to which one embodiment of the present invention is applied;

Fig. 2 is a block diagram showing the electrical construction of a tire pressure drop detecting device;

Fig. 3 is a flow chart for explaining the whole of tire pressure drop detection processing;

Fig. 4 is a flow chart for explaining the whole of tire pressure drop detection processing;

Figs. 5 and 6 are flow charts for explaining first initialization processing;

Fig. 7 is a diagram for explaining the relationship between the speed of a vehicle and lateral acceleration; and

Fig. 8 is a flow chart for explaining second initialization processing.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a block diagram showing the construction of a tire pressure drop detecting device to which one embodiment of the present invention is applied. The tire pressure drop detecting device determines whether or not the air pressure of any of four tires W_1, W_2, W_3, and W_4 provided in a four-wheel vehicle drops. The tires W_1 and W_2 respectively correspond to right and left front tires. The tires W_3 and W_4 respectively correspond to right and left rear tires.

A wheel speed sensor 1 is provided in relation to each of the tires W_1, W_2, W_3, and W_4. Output of the wheel speed sensors 1 are fed to a control unit 2.

A display 3 is connected to the control unit 2. The display 3 is for reporting the tire W_i (i = 1, 2, 3, 4) whose air pressure drops, and may be constituted by a liquid crystal display device, a plasma display device, a CRT (Cathode-Ray Tube), or the like.

An initializing switch 4 is also connected to the control unit 2. The initializing switch 4 is operated by a user in calculating initial correction factors K_j (j = 1, 2, 3) for eliminating the effect of an initial difference between the tires W_i. The initial difference means a variation in effective rolling radius within a fabrication tolerance between the tires Wi.

A steering sensor 5 for detecting the steering angle of a steering wheel (not shown) and a foot brake sensor 6 for determining whether or not a foot brake (not shown) is stepped on are further connected to the control unit 2.

Fig. 2 is a block diagram showing the electrical construction of the tire pressure drop detecting device. The control unit 2 is constituted by a microcomputer including an I/O interface 2a, a CPU 2b, a ROM 2c, a RAM 2d, and an EEPROM 2e.

The I/O interface 2a is required to deliver signals to external devices such as the wheel speed sensors 1, the initializing switch 4, the steering sensor 5 and the foot brake sensor 6. The CPU 2b is for performing various operation processing in accordance with a control operation program stored in the ROM 2c. The RAM 2d is one to which data or the like is temporarily written when the CPU 2b performs a control operation and from which the written data or the like is read out. A part of a storage area of the RAM 2d is utilized as counters 21, 22, and 23 used in initialization processing as described later. The EEPROM 2e stores data representing a relational expression for specifying the coasting range which is the range of the front/rear acceleration FRA of the vehicle at which the vehicle is judged to be coasting.

The wheel speed sensor 1 outputs a pulse signal corresponding to the speed of rotation of the tire W_i (hereinafter referred to as "wheel speed pulses"). In the CPU 2b, the rotational angular velocity F_i of each of the tires W_i is calculated for each predetermined sampling period ΔT (for example, ΔT = 1 (sec)) on the basis of the wheel speed pulses outputted from the wheel speed sensor 1.

Figs. 3 and 4 are flow charts for explaining processing for detecting the air pressure of a tire in the tire pressure drop detecting device. The CPU 2b operates in accordance with the predetermined program stored in the ROM 2c, so that the processing is repeatedly performed each sampling period ΔT by the control unit 2. In the following description,

it is presupposed that an objective vehicle is an FF (front engine front drive) vehicle.

The CPU 2b calculates the rotational angular velocity F_i of each of the tires W_i on the basis of wheel speed pulses outputted from the wheel speed sensor 1 (step S1 in Fig. 3). Judgment processing whether or not the rotational angular velocity F_i is rejected is then performed depending on whether or not the calculated rotational angular velocity F_i is likely to include an error.

More specifically, the rotational angular velocity F_i may include an error depending on the speed of the vehicle (hereinafter referred to as "vehicle speed"), the front/rear acceleration of each of the tires W_i, the turning radius of the vehicle and the lateral acceleration of the vehicle, or may include an error when the foot brake is stepped on.

More specifically, when the vehicle speed is significantly low, the detection precision of the wheel speed sensor 1 is significantly decreased, whereby it is highly possible that the calculated rotational angular velocity F_i includes an error. Further, when the front/rear acceleration of each of the tires W_i is relatively large, or the foot brake is stepped on, the effect of the slip of the tire W_i due to rapid acceleration or rapid deceleration of the vehicle, for example, is considered, whereby it is highly possible that the calculated rotational angular velocity F_i includes an error. Furthermore, when the turning radius of the vehicle is relatively small, or the lateral acceleration of the vehicle is relatively large, the tire W_i may laterally slip, whereby it is highly possible that the calculated rotational angular velocity F_i includes an error.

When it is thus highly possible that the rotational angular velocity F_i includes an error, it is preferable that the rotational angular velocity F_i is rejected without being employed for detecting the drop in air pressure.

On the other hand, the lateral acceleration of the vehicle is proportional to the square of the vehicle speed. In a case where the vehicle speed is calculated on the basis of the rotational angular velocity F_i, therefore, when the rotational angular velocity F_i varies, the effect of the variation on the lateral acceleration of the vehicle rapidly increases as the vehicle speed increases. Therefore, a large error may be included in the lateral acceleration of the vehicle.

One of causes of the variation in the rotational angular velocity F_i is the variation in the effective rolling radius of each of the tires W_i depending on the initial difference. Further, the difference between the distances of the tire on the inside of a corner and the tire on the outside of the corner (an inner and outer wheel difference) in a case where the vehicle is cornering is also a cause of the variation in the rotational angular velocity F_i.

Therefore, it is preferable that judgment of rejection based on the lateral acceleration of the vehicle is made after the effects of the initial difference and the inner and outer wheel difference are eliminated from the rotational angular velocity F_i.

Furthermore, when the effect of the inner and outer wheel difference is eliminated from the rotational angular velocity F_i, the turning radius of the vehicle is used, as described later, as a parameter for the elimination. When the turning radius of the vehicle which is being cornering is calculated on the basis of the rotational angular velocity F_i, an error may occur due to the movement of the load toward the outside of the corner in the turning radius of the vehicle. When the turning radius of the vehicle is found, therefore, the effect of the movement of the load on the vehicle must be eliminated. However, the amount of the movement of the load on the vehicle is proportional to the vehicle speed. When the vehicle speed is calculated on the basis of the rotational angular velocity F_i, therefore, the effect of the variation in the rotational angular velocity F_i depending on the initial difference on the turning radius of the vehicle increases as the vehicle speed increases. Therefore, it is preferable that judgment of rejection based on the turning radius of the vehicle is made after the effect of the initial difference is eliminated from the rotational angular velocity F_i.

In the present embodiment, therefore, judgment of rejection is made two times. Specifically, judgment of rejection based on the vehicle speed V_1, the front/rear acceleration FRA_i of each of the tires W_i and the foot brake is first made. Judgment of rejection based on the speed V2 of the vehicle, the lateral acceleration LA of the vehicle and the turning radius R of the vehicle is then made after the effects of the initial difference and the inner and outer wheel difference are eliminated.

The CPU 2b calculates the vehicle speed $\underline{V}$ and the front/rear acceleration FRA_i of each of the tires W_i after calculating the rotational angular velocity F_i, and further accepts an output SS of the foot brake sensor 6 (steps S2, S3, and S4). Further, when the front/rear acceleration FRA_i of each of the tires W_i is calculated, the front/rear acceleration FRA of the vehicle used in first initialization processing in the step S6 is also calculated.

The vehicle speed $\underline{V}$ is calculated on the basis of the speed V_i of each of the tires W_i. The speed V_i of each of the tires W_i is calculated in accordance with the following equation (20), where r is a constant corresponding to the effective rolling radius at the time of linear traveling, and is stored in the ROM 2c:

$$V_i = r \times F_i \tag{20}$$

The vehicle speed $\underline{V}$ is calculated by the following equation (21) on the basis of the calculated speed V_i of each of the tires W_i:

$$V = (V_1 + V_2 + V_3 + V_4) / 4 \tag{21}$$

The front/rear acceleration FRA_i of each of the tires W_i is calculated by the following equation (22), letting BV_i be the speed of the tire W_i calculated in the preceding sampling period:

$$FRA_i = (V_i - BV_i) / (\Delta T \times 9.8) \quad (22).$$

9.8 is inserted in the denominator in the foregoing equation (22) in order to convert the front/rear acceleration FRA_i of each of the tires W_i in G (gravity acceleration).

The front/rear acceleration FRA of the vehicle is calculated by the following equation (23) on the basis of the front/rear acceleration FRA_i of each of the tires W_i:

$$FRA = (FRA_1 + FRA_2 + FRA_3 + FRA_4) / 4 \quad (23).$$

The vehicle speed V and the front/rear acceleration FRA of the vehicle may be directly detected using sensors.

It is then judged whether or not the rotational angular velocity F_i calculated in the current sampling period is rejected on the basis of the vehicle speed V and the front/rear acceleration FRA_i of each of the tires W_i which are thus calculated, and the output SS of the foot brake sensor 5 (step S5). Specifically, when any one of the following conditions ① to ③ is satisfied, the rotational angular velocity F_i is rejected:

① $V < V_{TH}$ (for example, $V_{TH} = 10$ (km/h))
② MAX $\{|FRA_i|\} > A_{TH}$
(for example, $A_{TH} = 0.1\ g : g = 9.8$ (m/sec^2))
③ The foot brake is stepped on.

When the rotational angular velocity F_i is not rejected, the CPU 2b performs first initialization processing (step S6). The first initialization processing is processing for calculating initial correction factors K_j (j = 1, 2, 3) on condition that the vehicle is linearly coasting.

An initial correction factor K_1 is a factor for correcting the difference in effective rolling radius depending on the initial difference between the right and left front tires W_1 and W_2. An initial correction factor K_2 is a factor for correcting the difference in effective rolling radius depending on the initial difference between the right and left rear tires W_3 and W_4. An initial correction factor K_3 is a factor for correcting the difference in effective rolling radius depending on the initial difference between the front tire W_1 and the rear tire W_3. The initial correction factor K_3 calculated in the first initialization processing is stored as an initial correction factor BK_3 in the RAM 2d.

Thereafter, the CPU 2b corrects the speed V_i of each of the tires W_i using the initial correction factors K_j calculated in the first initialization processing (step S7). More specifically, the speed V_i of each of the tires W_i is corrected as expressed by the following equations (24) to (27), to acquire new speeds $V1_i$:

$$V1_1 = V_1 \quad (24)$$

$$V1_2 = K_1 \times V_2 \quad (25)$$

$$V1_3 = BK_3 \times V_3 \quad (26)$$

$$V1_4 = K_2 \times BK_3 \times V_4 \quad (27).$$

The vehicle speed V1 is calculated as expressed by the following equation (28) on the basis of the speed $V1_i$ of each of the tires W_i after the correction. Consequently, the speed V1 of the vehicle from which the effect of the initial difference has been eliminated is obtained.

$$V1 = (V1_1 + V1_2 + V1_3 + V1_4) / 4 \quad (28).$$

The turning radius R of the vehicle is then calculated on the basis of the vehicle speed V1 (step S8). More specifically, the turning radius R' of the vehicle is first calculated as expressed by the following equation (29). In the following equation (29), Tw is the tread width (the distance between the right wheel and the left wheel):

$$R' = \frac{Tw}{2} \times \frac{V1_4 + V1_3}{V1_4 - V1_3} \quad (29).$$

The turning radius R' of the vehicle is then subjected to such correction as to eliminate the effect of the movement of the load on the vehicle. Specifically, it is subjected to correction as expressed by the following equation (30):

$$R = R' \times \{u_1 + u_2 (V1_3 + V1_4)^2\} \quad (30).$$

In the equation (30), the following values are suitable as u_1 and u_2. In the following equation (33), Q is the load on the vehicle, H is the height from the ground plane of the tire to the center of gravity of the vehicle, and α is the rate of variation in the effective rolling radius of the tire with respect to the load:

$$u_1 = 1 \quad (31)$$

$$u_2 = \frac{1}{9.8} \times \frac{\beta}{2Tw} \quad (32)$$

$$\text{where } \beta = \frac{Q \times H \times \alpha}{Tw \times 100} \quad (33).$$

The CPU 2b then further subjects the speed $V1_i$ of each of the tires W_i from which the effect of the initial difference has been eliminated to correction for eliminating the effect of the inner and outer wheel difference on the basis of the calculated turning radius R of the vehicle (step S9). Specifically, the speed $V2_i$ of each of the tires W_i after the correction is calculated as expressed by the following equations (34) to (37), where WB is a wheel base:

$$V2_1 = \frac{|R|}{\sqrt{\{(R - Tw/2)^2 + WB^2\}}} \times V1_1 \quad (34)$$

$$V2_2 = \frac{|R|}{\sqrt{\{(R + Tw/2)^2 + WB^2\}}} \times V1_2 \quad (35)$$

$$V2_3 = \frac{|R|}{|R - Tw/2|} \times V1_3 \quad (36)$$

$$V2_4 = \frac{|R|}{|R + Tw/2|} \times V1_4 \quad (37).$$

The vehicle speed V2 is then calculated as expressed by the following equation (38) on the basis of the calculated speed $V2_i$ of each of the tires W_i after the correction (step S10 in Fig. 4). Consequently, the speed V2 from which the effects of the initial difference and the inner and outer wheel difference have been eliminated is obtained:

$$V2 = (V2_1 + V2_2 + V2_3 + V2_4) / 4 \quad (38).$$

The CPU 2b then calculates the lateral acceleration LA of the vehicle as expressed by the following equation (39) on the basis of the found vehicle speed V2 and the found turning radius R of the vehicle (step S10):

$$LA = V2^2 / (R \times 9.8) \quad (39).$$

9.8 is inserted in the denominator in order to convert the lateral acceleration LA of the vehicle in G (gravity acceleration).

Furthermore, it is judged whether or not the rotational angular velocity F_i calculated in the current sampling period is rejected on the basis of the vehicle speed V2, the lateral acceleration LA of the vehicle, and the turning radius R of the vehicle which are calculated in the foregoing manner (step S11). Specifically, when any one of the following three conditions ④ to ⑥ is satisfied, the rotational angular velocity F_i is rejected:

④ $V2 < V_{TH}$ (for example, V_{TH} = 10 (km/h))
⑤ $|LA| > LA_{TH}$ (for example, LA_{TH} = 0.4 g)
⑥ $|R| < R_{TH}$ (for example, R_{TH} = 30 (m)).

In the foregoing manner, the rotational angular velocity F_i which is likely to include an error is eliminated.

The CPU 2b then calculates the slip factor Rs as expressed by the following equation (40) on the basis of the speed $V2_i$ of each of the tires W_i found in the step S10 (step S12). The slip factor Rs is used in second initialization processing in the following step S13.

$$Rs = \frac{V2_1 + V2_2}{V2_3 + V2_4} - 1 \quad (40).$$

The second initialization processing is processing for calculating the initial correction factor K_3 on condition that the vehicle is cornering.

The initial correction factor K_3 is obtained using both the first initialization processing and the second initialization processing for two reasons. One is that the frequency of linear coasting at the time of usual traveling is relatively low, and another is to improve the precision of the initial correction factor K_3.

Specifically, the number of vehicles is large in a public road, so that the frequency of linear coasting at the time of usual traveling is limited. If the initial correction factor K_3 is calculated only at the time of linear coasting, there is a possibility that the initial correction factor K_3 cannot be rapidly calculated. If the second initialization processing is also used, the initial correction factor K_3 can be calculated if the vehicle is cornering even if it is not linearly coasting at the time of usual traveling.

Furthermore, examples of the public road include not only a road having many relatively straight roads such as a highway but also a road having many curves such as a mountain road. Consequently, the first initialization processing performed under the condition of linear coasting and the second initialization processing performed under the condition of cornering are both used, to obtain a precise initial correction factor K_3. More specifically, in the second initialization processing, the initial correction factor K_3 calculated in the second initialization processing and the initial correction factor K_3 calculated in the first initialization processing are compared with each other, and the initial correction factor K_3 which is higher in precision is taken as a final initial correction factor K_3. Further, the same comparison processing is also performed in the first initialization processing, and the initial correction factor K_3 which is higher in precision is taken as a final initial correction factor K_3. Consequently, a more precise initial correction factor K_3 is obtained.

The CPU 2b then again calculates parameters that have been calculated on the basis of an initial correction factor BK_3 obtained before the second initialization processing is performed using a correct initial correction factor K_3 (step S14). Specifically, the speeds $V2_3$ and $V2_4$ of the right and left rear tires W_3 and W_4 and the slip factor GRs are respectively calculated as expressed by the following equations (41) to (43). Consequently, the speeds $V3_3$ and $V3_4$ and the slip factor GRs from which the effect of the initial difference has been eliminated with high precision are obtained:

$$V3_3 = (K_3 / BK_3) \times V2_3 \quad (41)$$

$$V3_4 = (K_3 / BK_3) \times V2_4 \quad (42)$$

$$GRs = \{(BK_3 / K_3) \times (Rs + 1)\} - 1 \quad (43).$$

The CPU 2b then finds a judged value D for judging the drop in air pressure of the tire as expressed by the following equation (44) on the basis of the speeds $V2_1$ and $V2_2$ of the tires W_1 and W_2 and the speeds $V3_3$ and $V3_4$ of the tires W_3 and W_4 newly calculated (step S15):

$$D = \frac{\frac{V2_1 + V3_4}{2} - \frac{V2_2 + V3_3}{2}}{\frac{V2_1 + V2_2 + V3_3 + V3_4}{4}} \times 100 \quad (44).$$

The operation of the judged value D uses the speeds $V2_1$, $V2_2$, $V3_3$, and $V3_4$ of the respective tires W_i from which the effects of the initial difference and the inner and outer wheel difference of the tire Wi have been eliminated. However, the speeds $V2_1$, $V2_2$, $V3_3$, and $V3_4$ of the tires W_i vary even depending on not only the initial difference and the inner and outer wheel difference but also the lateral acceleration LA of the vehicle and the slip factor. Consequently, the effect of variation factors including the lateral acceleration LA of the vehicle and the slip factor are exerted on the judged value D.

Therefore, the CPU 2b subjects the judged value D to correction for eliminating the effects of the variation factors (step S16). Specifically, a corrected value C is found by the following equation (45). In the following equation (45), A1

and A2 are factors previously stored in the ROM 2c. The factors A1 and A2 are found upon trial traveling in a case where it is known that all the tires W_i have normal internal pressure.

$$C = A1 \times LA + A2 \times LA \times GRs \quad (45)$$

As expressed by the following equation (46), the corrected value C is subtracted from the judged value D. Consequently, a new judged value D' from which the effects of the variation factors have been eliminated are acquired:

$$D' = D - C \quad (46).$$

The CPU 2b then judges whether or not there is a tire W_i whose air pressure drops on the basis of the found judged value D' (step S17). Specifically, judgment thresholds D_{TH1} and D_{TH2} are set, and it is judged whether or not the judged value D' satisfies the following expression (47):

$$D' < -D_{TH1} \text{ or } D' > D_{TH2} \quad (47).$$

Although the judged value D' is found on the basis of the vehicle speeds $V2_1$, $V2_2$, $V3_3$, and $V3_4$ after the correction using the initial correction factors K_j as described above, the initial correction factors K_j are found by averaging processing as described later. Therefore, the larger the number of data used for averaging is, the higher the precision is. Before the initial correction factors K_j having sufficient precision are found, therefore, the precision of the judged value D' is changed. Consequently, in the present embodiment, the values of the judgment thresholds D_{TH1} and D_{TH2} are changed depending on the precision of the initial correction factors K_j. Processing for changing the judgment thresholds D_{TH1} and D_{TH2} will be described later.

When the judged value D' satisfies the condition given by the foregoing expression (47), it is judged that the air pressure of any one of the tires drops. On the other hand, when it is judged that the judged value D' does not satisfy the condition given by the foregoing expression (47), it is judged that there is no tire whose air pressure drops.

The CPU 2b thus determines whether or not the air pressure of the tire W_i drops while the vehicle is traveling. On the other hand, it makes the device more useful for a driver to report a tire W_i whose air pressure drops than to merely report that there is a tire W_i whose air pressure drops. Therefore, the CPU 2b specifies the tire W_i whose air pressure drops.

By using the judged value D' found by the foregoing equation (44), the following can be specified:

If $D' > 0$, the reduced pressure tire is W_1 or W_4.
If $D' < 0$, the reduced pressure tire is W_2 or W_3.

Furthermore, in this case, if the vehicle is in a linearly traveling state, the following can be specified:

If $V2_1 > V2_2$, the reduced pressure tire is W_1.
If $V2_1 < V2_2$, the reduced pressure tire is W_2.
If $V3_3 > V3_4$, the reduced pressure tire is W_3.
If $V3_3 < V3_4$, the reduced pressure tire is W_4.
If the tire W_i whose air pressure drops is specified, the result is displayed upon being outputted to the display 3.

The display 3 comprises indicator lamps respectively corresponding to the four tires W_1, W_2, W_3, and W_4, as shown in Fig. 2, for example. When it is detected that the air pressure of any one of the tires drops, the indicator lamp corresponding to the reduced pressure tire is turned on.

Figs. 5 and 6 are flow charts for explaining the first initialization processing. In the first initialization processing, the initial correction factors K_j are found on condition that the vehicle is linearly coasting, as described above. That is, the CPU 2b judges whether or not the vehicle is linearly traveling based on whether or not the output of the steering sensor 5 is within a predetermined allowable range (corresponding to a steering angle range of ± 2°, for example) (step T1 in Fig. 5). If the vehicle is not linearly traveling, the processing is terminated.

On the other hand, if the vehicle is linearly traveling, the initial correction factors K_1 and K_2 are calculated by averaging processing. More specifically, it is first judged whether or not a count value C1 of the counter 21 is not more than a predetermined maximum threshold MAX1 (for example, MAX1 = 900) (step T2). The count value C1 corresponds to the number of data used for calculating the initial correction factors K_1 and K_2, and is cleared every time the initializing switch 4 is operated.

If the count value C1 is less than the maximum threshold MAX1, the count value C1 is incremented by "1", after which the initial correction factors K_1 and K_2 are calculated as expressed by the following equations (48) and (49) (steps

T3 and T4). In the following equations (48) and (49), BK_1 and BK_2 are respectively the initial correction factors K_1 and K_2 found in the preceding sampling period and stored in the RAM 2d:

$$K_1 = \frac{C1 - 1}{C1} \times BK_1 + \frac{1}{C1} \times \frac{F_1}{F_2} \quad (48)$$

$$K_2 = \frac{C1 - 1}{C1} \times BK_2 + \frac{1}{C1} \times \frac{F_3}{F_4} \quad (49).$$

The initial correction factors K_1 to K_2 are respectively found as the average of C1 ratios of the rotational angular velocities F_1 and F_2 of the right and left front tires W_1 and W_2 and the average of C1 ratios of the rotational angular velocities F_3 and F_4 of the right and left rear tires W_3 and W_4 at the time of linear traveling of the vehicle. Consequently, it is possible to obtain a precise initial correction factor K_1 faithfully representing a difference in effective rolling radius between the right and left front tires W_1 and W_2, and obtain a precise initial correction factor K_2 faithfully representing a difference in effective rolling radius between the right and left rear tires W_3 and W_4.

The CPU 2b then judges whether or not the count value C1 is less than a predetermined minimum threshold MIN1 (for example, MIN1 = 60) (step T5). If the count value C1 is less than the minimum threshold MIN1, it is considered that the precision of the initial correction factors K_1 and K_2 is still insufficient. Therefore, the program directly proceeds to the step T16 shown in Fig. 6 without performing the processing in the steps T6 to T14 using the initial correction factors K_1 and K_2. If the count value C1 is not less than the minimum threshold MIN1, it is considered that the precision of the initial correction factors K_1 and K_2 is sufficiently given to some extent, whereby the program proceeds to the step T6.

If it is judged that the count value C1 has reached the maximum threshold MAX1 in the step T2, it is considered that the precision of the initial correction factors K_1 and K_2 is sufficient. Therefore, the program directly proceeds to the step T6 without the CPU 2b incrementing the count value C1 and calculating the initial correction factors K_1 and K_2.

The CPU 2b performs calculation processing of an initial correction factor K_3 in the steps T6 to T14. The calculated initial correction factor K_3 is taken as a final initial correction factor K_3 only when it is higher in precision than the initial correction factor K_3 calculated in second initialization processing in the preceding period. For convenience, the initial correction factor K_3 calculated in the first initialization processing before judging the precision is taken as an initial correction factor Kx. Further, the initial correction factor K_3 calculated in the second initialization processing is taken as a final initial correction factor K_3 only when it is higher in precision than the initial correction factor K_3 calculated in the first initialization processing. For convenience, therefore, the initial correction factor K_3 calculated before judging the precision in the second initialization processing is taken as an initial correction factor Ky.

An initial correction factor Kx is obtained as the average of initial correction factors Kx which have been calculated by the preceding sampling period, similarly to the initial correction factors K_1 and K_2. Collection of initial correction factors Kx whose number causes the precision to be sufficiently given is sufficient.

Therefore, the CPU 2b judges whether or not the count value C2 of the counter 22 is less than a predetermined maximum threshold MAX2 (for example, MAX2 = 300) (step T6). The count value C2 corresponds to the number of data used for calculating the initial correction factor Kx, and is cleared every time the initializing switch 4 is operated.

If the count value C2 reaches the maximum threshold MAX2, it is considered that the precision of the initial correction factor Kx is sufficient. Therefore, the program directly proceeds to the step T16 shown in Fig. 6 without calculating the initial correction factor K_x. On the other hand, if the count value C2 is less than the maximum threshold MAX2, calculation processing of the initial correction factor Kx is performed.

The initial correction factor Kx represents a difference in effective rolling radius between the front tire W_1 and the rear tires W_3. If the driving tires W_1 and W_2 slip at the time of driving or at the time of braking, the precision is decreased. Therefore, the CPU 2b performs judgment processing as to whether or not the vehicle is coasting prior to calculating the initial correction factor Kx (steps T7 to T13).

It is judged whether or not the vehicle is coasting depending on whether or not the front/rear acceleration FRA of the vehicle is within a predetermined coasting range. The coasting range takes a maximum value and a minimum value which differ depending on the vehicle speed. Specifically, the higher the vehicle speed is, the narrower the coasting range becomes, as shown by Fig. 7. In the present embodiment, therefore, it can be reliably judged whether or not the vehicle is coasting irrespective of the vehicle speed by previously finding the coasting range corresponding to the vehicle speed.

The coasting range corresponding to the vehicle speed is acquired by causing the vehicle to coast on a straight level road by trial. More specifically, the vehicle speed at the time of coasting and the front/rear acceleration of the vehicle are calculated. Such work is performed with respect to various vehicle speeds, so that a lot of data are collected. A method of least squares is applied to the data, to find a quadratic expression as given by the following equation (50). In

the following equation (50), $\alpha 1$ and $\alpha 2$ are constants:

$$FRA = \alpha 1 \times V^2 + \alpha 2 \quad (50).$$

Furthermore, quadratic expressions obtained by shifting the quadratic expression by β (for example, $\beta = 0.2$ g) in both positive and negative directions are found. They are respectively expressed by the following equations (51) and (52):

$$G1 = \alpha 1 \times V^2 + \alpha 2 + \beta \quad (51)$$

$$G2 = \alpha 1 \times V^2 + \alpha 2 - \beta \quad (52).$$

The range put between the quadratic expressions is the oasting range. The two quadratic expressions representing the coasting range are stored in the EEPROM 2e.

On the other hand, strictly speaking, the vehicle which is being coasting should be in a decelerated state to some extent. Consequently, in view of the principle, the maximum value Gb1 of acceleration at which it can be judged that the vehicle is coasting is zero. The minimum value Gb2 of acceleration at which it can be judged that the vehicle is coasting is set to a suitable value (for example, -0.04 g). The maximum value Gb1 and the minimum value Gb2 are stored in the EEPROM 2e, similarly to the two quadratic expressions representing the coasting range.

The CPU 2b substitutes the vehicle speed $\underline{V}$ found in the step S2 shown in Fig. 3 into the foregoing equation (51) in the step T7. Consequently, the maximum value G1 is acquired. It is judged whether or not the maximum value G1 is not less than the maximum value Gb1 (step T8). If the maximum value G1 is not less than the maximum value Gb1, the maximum value is forcedly corrected to Gb1 (step T9). On the other hand, if the maximum value G1 is less than the maximum value Gb1, G1 is taken as the maximum value as it is.

The CPU 2b then substitutes the vehicle speed $\underline{V}$ into the foregoing equation (49). As a result, the minimum value G2 is acquired (step T10 in Fig. 6). It is judged whether or not the acquired minimum value G2 is not less than the minimum value Gb2 (step T11). If the minimum value G2 is not less than the minimum value Gb2, the minimum value is forcedly corrected to Gb2 (step T12). On the other hand, if the minimum value G2 is less than the minimum value Gb2, G2 is taken as the minimum value as it is.

The coasting range in the current sampling period is thus obtained.

The CPU 2b then judges whether or not the front/rear acceleration FRA of the vehicle which is calculated in the current sampling period is within the obtained coasting range (step T13).

If the front/rear acceleration FRA of the vehicle which is calculated in the current sampling period is not within the coasting range, it cannot be considered that the vehicle is coasting. Therefore, the program directly proceeds to the step T16 without calculating the initial correction factor Kx. On the other hand, if the front/rear acceleration FRA of the vehicle is within the coasting range, the count value C2 is incremented by "1", and the initial correction factor Kx is calculated as expressed by the following equation (53) (steps T14 and T15). In the following equation (53), BKx is an initial correction factor Kx calculated in the preceding sampling period and stored in the RAM 2d:

$$Kx = \frac{C2 - 1}{C2} \times BKx + \frac{1}{C2} \times \frac{F_1 + K_1 \times F_2}{F_3 + K_2 \times F_4} \quad (53).$$

The CPU 2b then compares the calculated initial correction factor Kx with the initial correction factor Ky calculated in the second initialization processing in the preceding sampling period in order to obtain the final initial correction factor K_3. As a criterion for comparison, the count value C2 of the counter 22 corresponding to the number of data used for calculating the initial correction factor Kx and a count value C3 of the counter 23 corresponding to the number of data used for calculating the initial correction factor Ky are used. That is, the larger the number of data used for averaging is, the higher the precision is because the effect of noise can be eliminated.

Therefore, the CPU 2b judges whether or not the count value C3 of the counter 23 is not less than a predetermined minimum value MIN3 (for example, MIN3 = 50) or whether or not the count value C3 is not less than the count value C2 (step T16).

If the count value C3 is not less than the minimum threshold MIN3, or the count value C3 is not less than the count value C2, it is considered that the initial correction factor Ky is higher in precision than the initial correction factor Kx, whereby the initial correction factor Ky is selected as a final initial correction factor K_3 (step T17). On the other hand, if the count value C3 is less than the minimum threshold MIN3, and the count value C3 is less than the count value C2, it is considered that the initial correction factor Kx is higher in precision than the initial correction factor Ky, whereby the initial correction factor Kx is selected as the final initial correction factor K_3 (step T18). The selected initial correction fac-

tor K_3 is stored as an initial correction factor BK_3 in the RAM 2d (step T19).

Fig. 8 is a flow chart for explaining the second initialization processing. In the second initialization processing, the initial correction factor K_y is calculated by averaging past initial correction factors Ky which have been calculated by the preceding sampling period. Therefore, the CPU 2b judges whether or not the count value C3 of the counter 23 is less than a predetermined maximum threshold MAX3 (for example, MAX3 = 150) (step U1). If the count value C3 reaches the maximum threshold MAX3, it is considered that the initial correction factor Ky is the average of data whose number causes the precision to be sufficiently given, whereby the processing is terminated. On the other hand, if the count value C3 is less than the maximum threshold MAX3, the program proceeds to processing in the subsequent step U2.

The CPU 2b judges whether or not the vehicle is cornering, and the count value C1 is not less than the minimum threshold MIN1' (for example, MIN1' = 300).

It is judged whether or not the vehicle is cornering depending on whether or not the lateral acceleration LA of the vehicle satisfies the condition given by the following expression (54). In the following expression (54), LA1 = 0.08g, and LA2 = 0.4g:

$$LA1 < |LA| < LA2 \quad (54).$$

The reason why judgment whether or not the count value C1 is not less than the minimum threshold MIN1' is used as one of criteria for judgment is that the initial correction factors K_1 and K_2 are used for calculating the lateral acceleration LA of the vehicle, as expressed by the foregoing equations (39), (38), (34) to (37), and (24) to (27). That is, the larger the number of data used for averaging is, the higher the precision of the initial correction factors K_1 and K_2 is. If the number of data is small, therefore, the precision of the lateral acceleration LA of the vehicle is not sufficiently given. In this case, erroneous judgment may be made in the step U2, accordingly. Further, if the precision of the lateral acceleration LA of the vehicle is low, the precision of the initial correction factor Ky found by the following equation (56) is also decreased.

The lateral acceleration LA of the vehicle can be also obtained from the output of the steering sensor 5 and the vehicle speed. The lateral acceleration LA of the vehicle thus obtained has no relation with the initial correction factors K_1 and K_2. In this case, therefore, the necessity of the criterion for judgment whether or not the count value C1 is not less than the minimum threshold MIN1' is eliminated.

If the vehicle is not cornering, or the count value C1 is less than the minimum threshold MIN1', it is considered that the initial correction factor Ky cannot be calculated with high precision, whereby the processing is terminated. On the other hand, if the vehicle is cornering, and the count value C1 is not less than the minimum threshold MIN1', the program proceeds to the subsequent step U3.

The CPU 2b judges whether or not the slip factor Rs of the driving tires W_1 and W_2 calculated in the step S12 shown in Fig. 4 satisfies the following expression (55) in the step U3. The judgment processing is based on the discovery of the inventors of the present application that the precision of the initial correction factor Ky is decreased when the slip factor Rs does not satisfy the following expression (55). In the following expression (55), Rs1 and Rs2 are constants, and Rs1 = 0 and Rs2 = 0.008, for example:

$$Rs1 < Rs < Rs2 \quad (55).$$

If the foregoing expression (55) is not satisfied, the processing is terminated. On the other hand, if the foregoing expression (55) is satisfied, the count value C3 of the counter 23 is incremented by "1", and the judged value D and the slip factor Rs are calculated. Further, the initial correction factor Ky is calculated on the basis of the judged value D and the slip factor Rs which are calculated (steps U4, U5, U6, and U7).

More specifically, the initial correction factor Ky is calculated in accordance with the following equation (56) derived from an equation obtained by modifying a correction expression for correcting cornering relating to the judged value D and an expression for calculating the slip factor Rs. In the following equation (56), BKy is an initial correction factor Ky calculated in the preceding sampling period and stored in the RAM 2d:

$$Ky = \frac{C3 - 1}{C3} \times BKy + \frac{1}{C3} \times \frac{1}{Rs + 1} \times \frac{F_1 + K_1 \times F_2}{F_3 + K_2 \times F_4} \quad (56).$$

The judged value D is calculated as in the foregoing equation (44). Further, the slip factor Rs is calculated in accordance with the forgoing equation (12) on the basis of the judged value D and the lateral acceleration LA of the vehicle which are calculated.

Thereafter, the CPU 2b substitutes the calculated slip factor Rs into the foregoing equation (56). Consequently, the initial correction factor Ky is obtained.

The CPU 2b then compares the precision of the calculated initial correction factor Ky with the precision of the initial correction factor Kx calculated in the first initialization processing in the current sampling period in order to obtain the final initial correction factor K_3. As a criterion for comparison, the count value C2 of the counter 22 corresponding to the number of data used for calculating the initial correction factor Kx and the count value C3 of the counter 23 corresponding to the number of data used for calculating the initial correction factor Ky are used, as in the first initialization processing. That is, the CPU 2b judges whether or not the count value C3 of the counter 23 is not less than the minimum threshold MIN3, or the count value C3 is not less than the count value C2 (step U8).

If the count value C3 is not less than the minimum threshold MIN3, or the count value C3 is not less than the count value C2, it is considered that the initial correction factor Ky is higher in precision than the initial correction factor Kx, whereby the initial correction factor Ky is selected as the final initial correction factor K_3 (step U9). On the other hand, if the count value C3 is less than the minimum threshold MIN3, and the count value C3 is less than the count value C2, it is considered that the initial correction factor Kx is higher in precision than the initial correction factor Ky, whereby the initial correction factor Kx is selected as the final initial correction factor K_3 (step U10).

Description is now made of processing for changing the judgment thresholds D_{TH1} and D_{TH2} used in the air pressure drop judgment processing in the step S17 shown in Fig. 4. As described in the foregoing, the judgment thresholds D_{TH1} and D_{TH2} are changed depending on the precision of the initial correction factor K_j. The precision of the initial correction factor K_j is represented by the number of data used for calculating the initial correction factor K_j, as described in the first initialization processing and the second initialization processing. In the processing for changing the judgment thresholds D_{TH1} and D_{TH2}, therefore, the count values C1, C2, and C3 of the counters 21, 22, and 23 are used as parameters for judging the precision of the initial correction factor K_j.

The CPU 2b judges whether or not the first condition under which the count value C1 reaches the maximum threshold MAX1, and the count value C3 reaches the maximum threshold MAX3 is satisfied. That is, it is judged whether or not the calculation of the initial correction factor K_j is terminated.

The reason why in the first condition, the count value C3 corresponding to the number of data used for calculating the initial correction factor Ky is used as a criterion for judgment whether or not the calculation of the initial correction factor K_3 is terminated is that the precision of the initial correction factor Kx is decreased at the time of climbing. That is, even if the front/rear acceleration FRA of the vehicle is in the coasting range at the time of climbing, driving forces are transmitted to the driving tires W_1 and W_2, whereby the vehicle is not actually coasting. In this case, therefore, the precision of the initial correction factor Kx is low.

If the first condition is satisfied, it is considered that the precision of the initial correction factor K_j is sufficient, whereby a reference value D_0 (for example, $D_0 = 0.1$) is set as the judgment thresholds D_{TH1} and D_{TH2}. On the other hand, if the first condition is not satisfied, the CPU 2b examines whether the precision of the initial correction factor K_j is relatively high or low or too low to judge the drop in air pressure.

Specifically, the CPU 2b first judges whether or not the second condition under which the count value C1 is not less than m_1 (for example, $m_1 = 2/3$) times the maximum threshold MAX1, and the count value C3 is not less than m_1 times the maximum threshold MAX3 is satisfied in order to examine whether or not the precision of the initial correction factor K_j is relatively high. If the second condition is satisfied, it is considered that the precision of the initial correction factor K_j is relatively high, whereby a value which is n_1 (for example, $n_1 = 1.33$) times the reference value D_0 is set as the judgment thresholds D_{TH1} and D_{TH2}.

On the other hand, if the second condition is not satisfied, it is then judged whether or not the third condition under which the count value C1 is more than m_2 ($m_2 < m_1$; $m_2 = 1/3$, for example) times the maximum threshold MAX1, and the count value C2 is not less than m_2 times the maximum threshold MAX2, or the count value C3 is not less than m_2 times the maximum threshold MAX3 is satisfied in order to examine whether the precision of the initial correction factor K_j is relatively low or too low.

If the third condition is satisfied, it is considered that the precision of the initial correction factor K_j is relatively low but is not too low, whereby a value which is n_2 ($n_2 > n_1$; $n_2 = 1.66$, for example) times the reference value D_0 is set as the judgment thresholds D_{TH1} and D_{TH2}. On the other hand, if the third condition is not satisfied, it is considered that the precision of the initial correction factor K_j is too low, whereby the judgement thresholds D_{TH1} and D_{TH2} are not set. In this case, no air pressure drop judgement processing is performed.

As described in the foregoing, according to the present embodiment, when the vehicle is in usual traveling, it is detected that the vehicle is linearly traveling. At this time, the initial correction factors K_1 and K_2 are calculated. Further, when the vehicle is in usual traveling, it is detected that the vehicle is linearly coasting. At this time, the initial correction factor Kx is calculated. Further, when the vehicle is in usual traveling, it is detected that the vehicle is cornering. At this time, the initial correction factor Ky is calculated. One of the initial correction factors Kx and Ky which is higher in precision is taken as the final initial correction factor K_3.

Even if the user does not intentionally cause the vehicle to linearly coast, therefore, it is possible to obtain precise initial correction factors K_j. Moreover, with respect to the initial correction factor K_3, one of the initial correction factors Kx and Ky, which is higher in precision, respectively calculated in different traveling states is taken as the initial correc-

tion factor K_3, whereby the precision thereof is higher, as compared with that in a case where only the calculated value in either one of the traveling states is used.

The precise initial correction factor K_j can be thus simply obtained. Therefore, it is possible to significantly reduce the burden on the user as well as to improve the traffic safety.

Although description has been made of one embodiment of the present invention, the present invention is not limited to the above-mentioned embodiment. In the above-mentioned embodiment, processing for calculating the initial correction factor Kx is used when the vehicle is linearly coasting, while processing for calculating the initial correction factor Ky is used in a case where the vehicle is cornering, and one of the initial correction factors Kx and Ky which is higher in precision is selected as the final initial correction factor K_3. However, only either one of the two processing may be performed, and the initial correction factor Kx or Ky may be used as the initial correction factor K_3 as it is. Further, the user may be manually selectable as to which of the processing should be performed. Even by such construction, it is possible to simply calculate the precise initial correction factor K_3.

Although the present invention has been described and illustrated in detail, it is clearly understood that the description is by way of illustration and example only and is not to be taken by way of limitation.

Claims

1. A device for operating a correction factor for correcting an output of rotational angular velocity detecting means (1) for detecting the rotational angular velocities of four tires mounted on a vehicle, the device comprising:

   means (T1) for judging whether or not the vehicle is linearly traveling; and
   means (T4) for calculating, if it is judged that the vehicle is linearly traveling, an initial correction factor K_1 for eliminating an effect of a difference in effective rolling radius depending on an initial difference between right and left front tires on the rotational angular velocities of the tires and an initial correction factor K_2 for eliminating an effect of a difference in effective rolling radius depending on an initial difference between right and left rear tires on the rotational angular velocities of the tires on the basis of the output of the rotational angular velocity detecting means (1).

2. A device according to claim 1, further comprising:

   means (T13) for judging whether or not the vehicle is coasting, and
   means (T15) for calculating, if it is judged that the vehicle is linearly traveling and it is judged that the vehicle is coasting, an initial correction factor K_3 for eliminating an effect of a difference in effective rolling radius depending on an initial difference between the front tire and the rear tire on the rotational angular velocities of the tires on the basis of the calculated initial correction factors K_1 and K_2 and the output of the rotational angular velocity detecting means (1).

3. A device according to claim 1 or 2, further comprising:

   means (U3) for judging whether or not the vehicle is cornering,
   means (U6) for finding a slip factor Rs of the tire, and
   means (U7) for calculating, if it is judged that the vehicle is cornering, an initial correction factor K_3 for eliminating an effect of a difference in effective rolling radius depending on an initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means (1), the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined operation expression.

4. A device according to claim 3, further comprising:

   means (U5) for calculating a judged value D for judging a drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means (1),
   the means (U6) for finding the slip factor Rs substituting a lateral acceleration LA of the vehicle and the judged value D into a predetermined operation expression, to find the slip factor Rs of the tire.

5. A device according to claim 1 or 2, further comprising:

   means (S10) for calculating a lateral acceleration LA of the vehicle on the basis of the output of the rotational angular velocity detecting means (1),

means (U5) for calculating a judged value D for judging a drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means (1),

means (U6) for substituting the lateral acceleration LA of the vehicle and the judged value D thus calculated into a predetermined first operation expression, to find a slip factor Rs of the tire, and

means (U7) for calculating, if it is judged that the vehicle is cornering, an initial correction factor K_3 for eliminating an effect of a difference in effective rolling radius depending on an initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means, the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined second operation expression.

6. A device according to any one of claims 3 to 5, further comprising:

means (U3) for judging whether or not the slip factor Rs takes a value within a predetermined range, and

means (U3) for inhibiting the calculation of the initial correction factor K_3 if it is judged that the slip factor Rs takes a value within the predetermined range.

7. A device according to claim 1, further comprising:

means (T13) for judging whether or not the vehicle is coasting,

means (T15) for calculating, if it is judged that the vehicle is linearly traveling and it is judged that the vehicle is coasting, an initial correction factor Kx for eliminating an effect of a difference in effective rolling radius depending on an initial difference between the front tire and the rear tire on the rotational angular velocities of the tires on the basis of the calculated initial correction factors K_1 and K_2 and the output of the rotational angular velocity detecting means;

means (U2) for judging whether or not the vehicle is cornering,

means (U6) for calculating a slip factor Rs of the tire,

means (U7) for calculating, if it is judged that the vehicle is cornering, an initial correction factor Ky for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means (1), the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined operation expression;

means (T16, U8) for judging which of the calculated initial correction factors Kx and Ky is higher in precision, and

means (T17, T18, U9, U10) for taking the initial correction factor which is judged to be higher in precision as a final initial correction factor K_3 for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires.

8. A device according to claim 7, further comprising

means (U5) for calculating a judged value D for judging a drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means (1),

the means (U6) for finding the slip factor Rs substituting a lateral acceleration LA of the vehicle and the calculated judged value D into a predetermined operation expression, to find the slip factor Rs of the tire.

9. A device according to claim 1, further comprising;

means (T13) for judging whether or not the vehicle is coasting,

means (T15) for calculating, if it is judged that the vehicle is linearly traveling and it is judged that the vehicle is coasting, an initial correction factor Kx for eliminating an effect of a difference in effective rolling radius depending on an initial difference between the front tire and the rear tire on the rotational angular velocities of the tires on the basis of the calculated initial correction factors K_1 and K_2 and the output of the rotational angular velocity detecting means (1);

means (S10) for calculating a lateral acceleration LA of the vehicle on the basis of the output of the rotational angular velocity detecting means (1),

means (U5) for calculating a judged value D for judging a drop in air pressure of the tire on the basis of the output of the rotational angular velocity detecting means (1),

means (U6) for substituting the lateral acceleration LA of the vehicle and the judged value D thus calculated into a predetermined first operation expression, to calculate the slip factor Rs of the tire,

means (U2) for judging whether or not the vehicle is cornering on the basis of the calculated lateral acceleration LA of the vehicle,

means (U7) for calculating, if it is judged that the vehicle is cornering, an initial correction factor Ky for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires by substituting the output of the rotational angular velocity detecting means (1), the calculated initial correction factors K_1 and K_2, and the calculated slip factor Rs into a predetermined second operation expression;

means (T16, U8) for judging which of the calculated initial correction factors Kx and Ky is higher in precision, and

means (T17, T18, U9, U10) for taking the initial correction factor which is higher in precision as a final initial correction factor K_3 for eliminating the effect of the difference in effective rolling radius depending on the initial difference between the front tire and the rear tire on the rotational angular velocities of the tires.

10. A device according to any one of claims 7 to 9, further comprising;

means (U3) for judging whether or not the slip factor Rs takes a value within a predetermined range, and

means (U3) for inhibiting the calculation of the initial correction factor K_3 if it is judged that the slip factor Rs takes a value within the predetermined range.

11. A device according to any one of claims 7 to 10, wherein

the means (T15) for calculating the initial correction factor Kx includes means for subjecting a plurality of data to an average operation,

the means (U7) for calculating the initial correction factor Ky includes means for subjecting a plurality of data to an average operation, and

the means (T16, U8) for judging which of the initial correction factors Kx and Ky is higher in precision includes means for judging the precision on the basis of the numbers of the data which have been subjected to the respective average operations.

FIG. 1

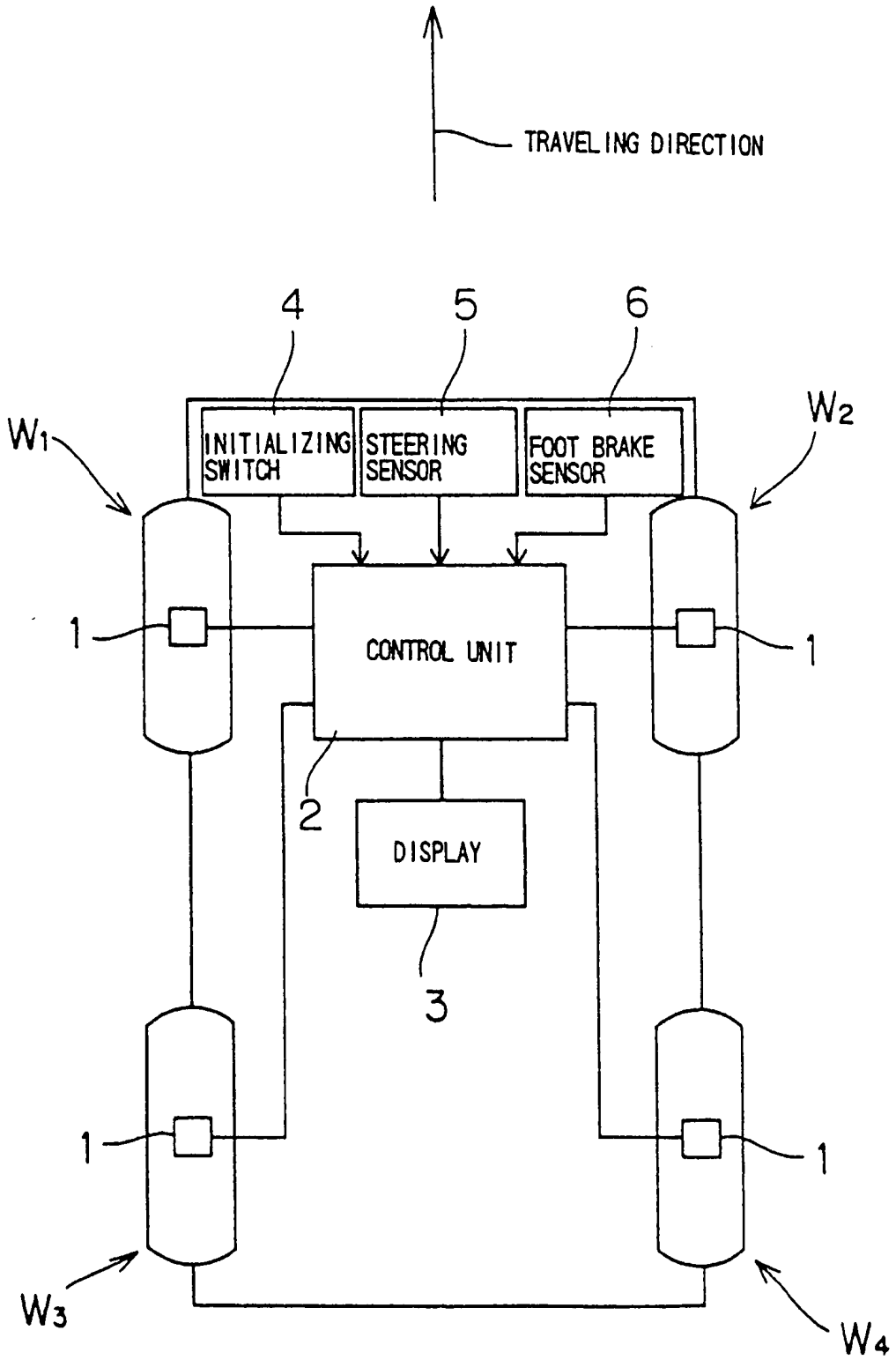

TRAVELING DIRECTION
4
5
6
INITIALIZING SWITCH
STEERING SENSOR
FOOT BRAKE SENSOR
W1
W2
1
CONTROL UNIT
1
2
DISPLAY
3
1
1
W3
W4

FIG. 2

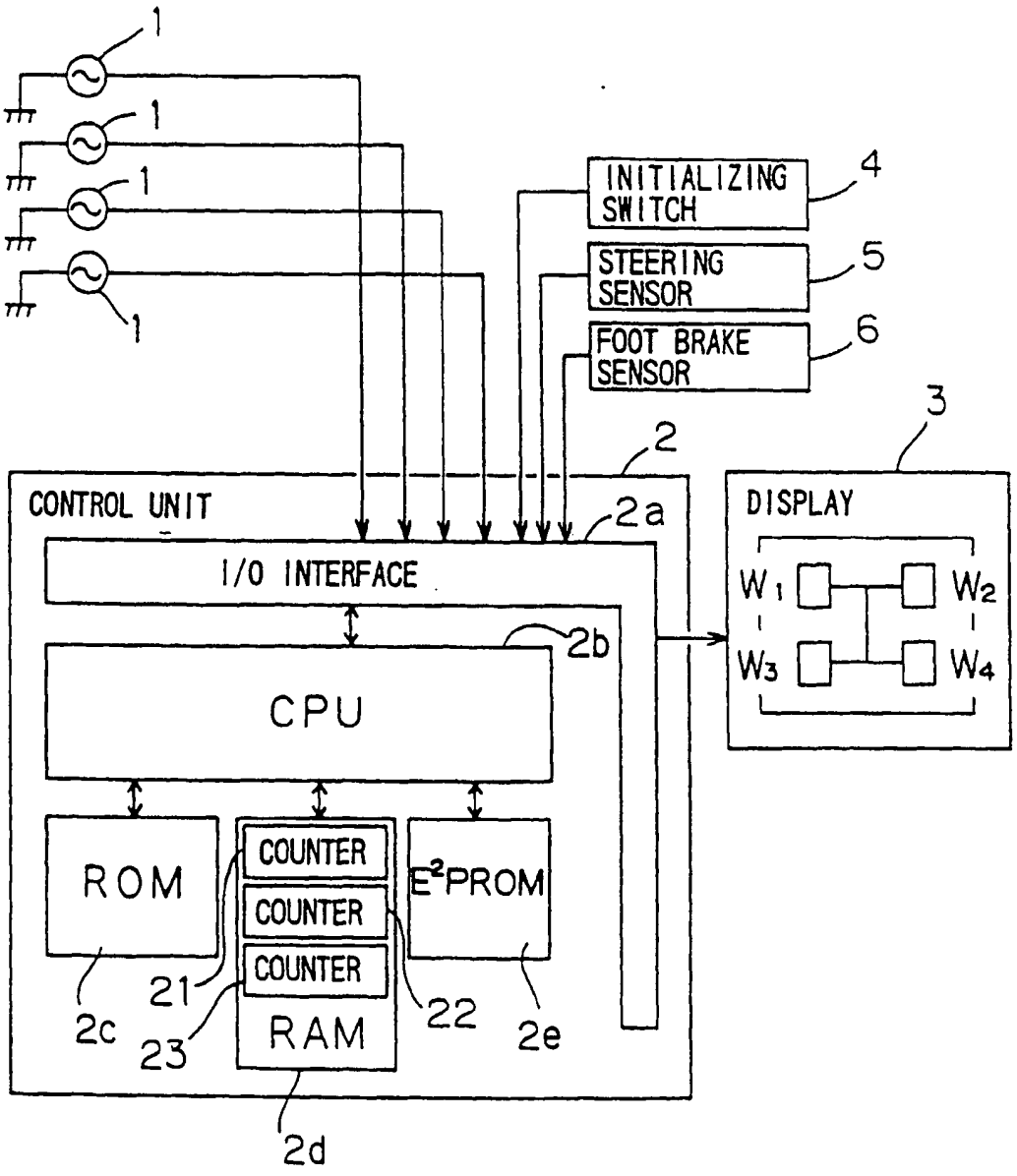

1
1
1
1
INITIALIZING SWITCH
4
STEERING SENSOR
5
FOOT BRAKE SENSOR
6
3
2
CONTROL UNIT
2a
DISPLAY
I/O INTERFACE
W1
W2
W3
W4
2b
CPU
ROM
COUNTER
COUNTER
COUNTER
RAM
E2PROM
21
22
23
2c
2e
2d

FIG. 3

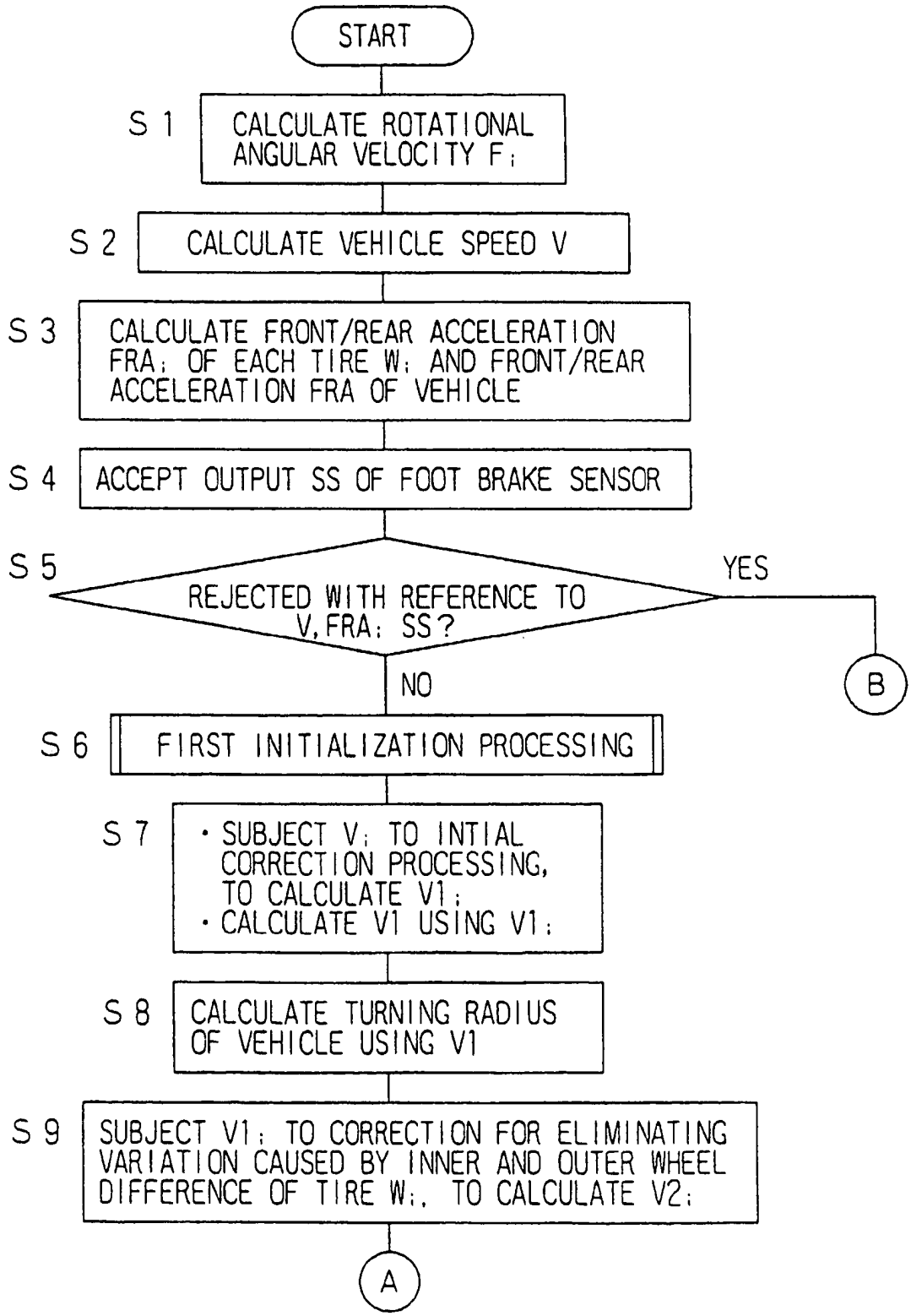

START
S 1
CALCULATE ROTATIONAL ANGULAR VELOCITY Fi
S 2
CALCULATE VEHICLE SPEED V
S 3
CALCULATE FRONT/REAR ACCELERATION FRAi OF EACH TIRE Wi AND FRONT/REAR ACCELERATION FRA OF VEHICLE
S 4
ACCEPT OUTPUT SS OF FOOT BRAKE SENSOR
S 5
REJECTED WITH REFERENCE TO V, FRAi SS?
YES
NO
B
S 6
FIRST INITIALIZATION PROCESSING
S 7
• SUBJECT Vi TO INTIAL CORRECTION PROCESSING, TO CALCULATE V1i
• CALCULATE V1 USING V1i
S 8
CALCULATE TURNING RADIUS OF VEHICLE USING V1
S 9
SUBJECT V1i TO CORRECTION FOR ELIMINATING VARIATION CAUSED BY INNER AND OUTER WHEEL DIFFERENCE OF TIRE Wi, TO CALCULATE V2i
A

FIG. 4

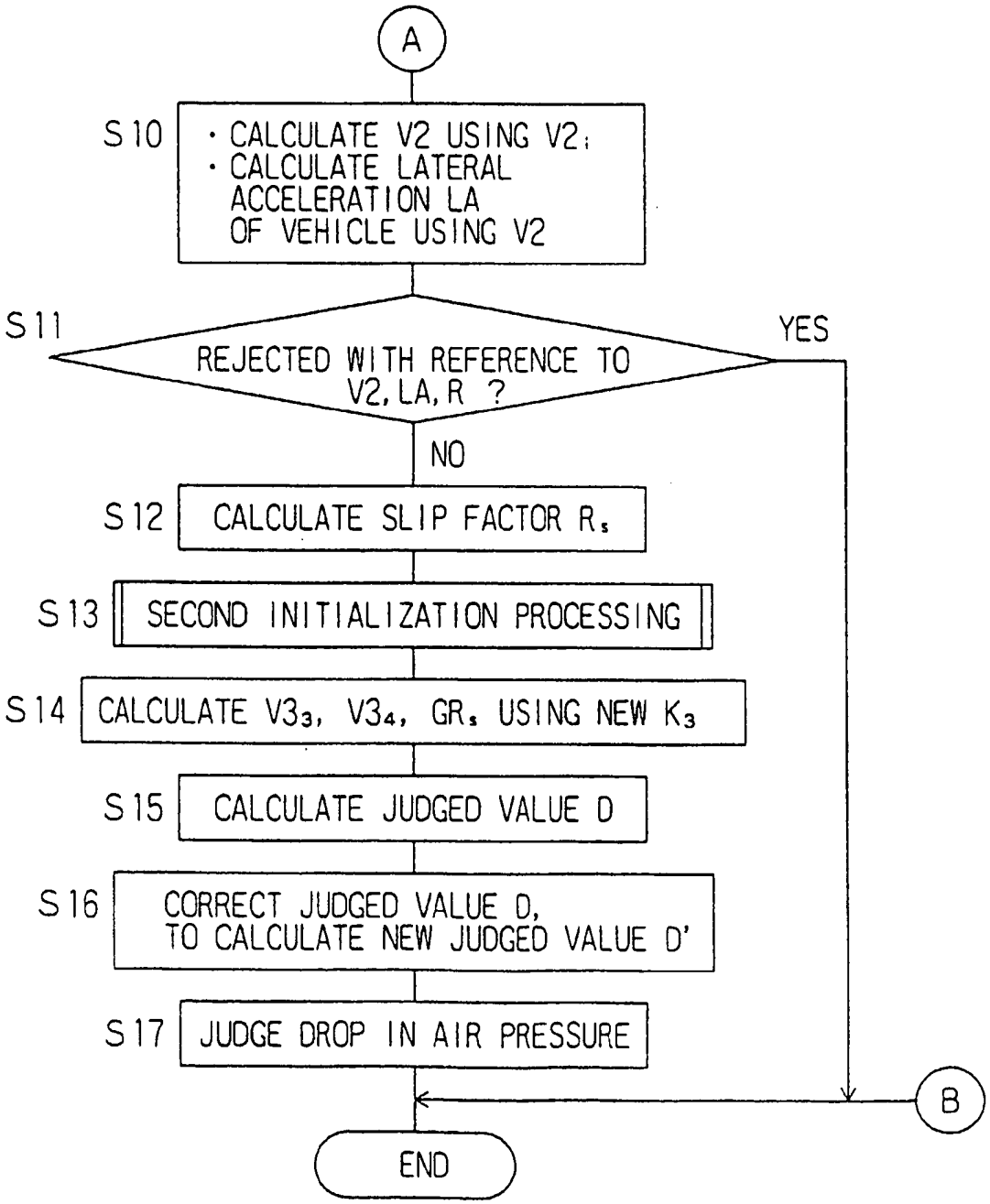

A
S10
· CALCULATE V2 USING V2ᵢ
· CALCULATE LATERAL ACCELERATION LA OF VEHICLE USING V2
S11
REJECTED WITH REFERENCE TO V2, LA, R ?
YES
NO
S12
CALCULATE SLIP FACTOR Rₛ
S13
SECOND INITIALIZATION PROCESSING
S14
CALCULATE V3₃, V3₄, GRₛ USING NEW K₃
S15
CALCULATE JUDGED VALUE D
S16
CORRECT JUDGED VALUE D, TO CALCULATE NEW JUDGED VALUE D'
S17
JUDGE DROP IN AIR PRESSURE
B
END

FIG. 5

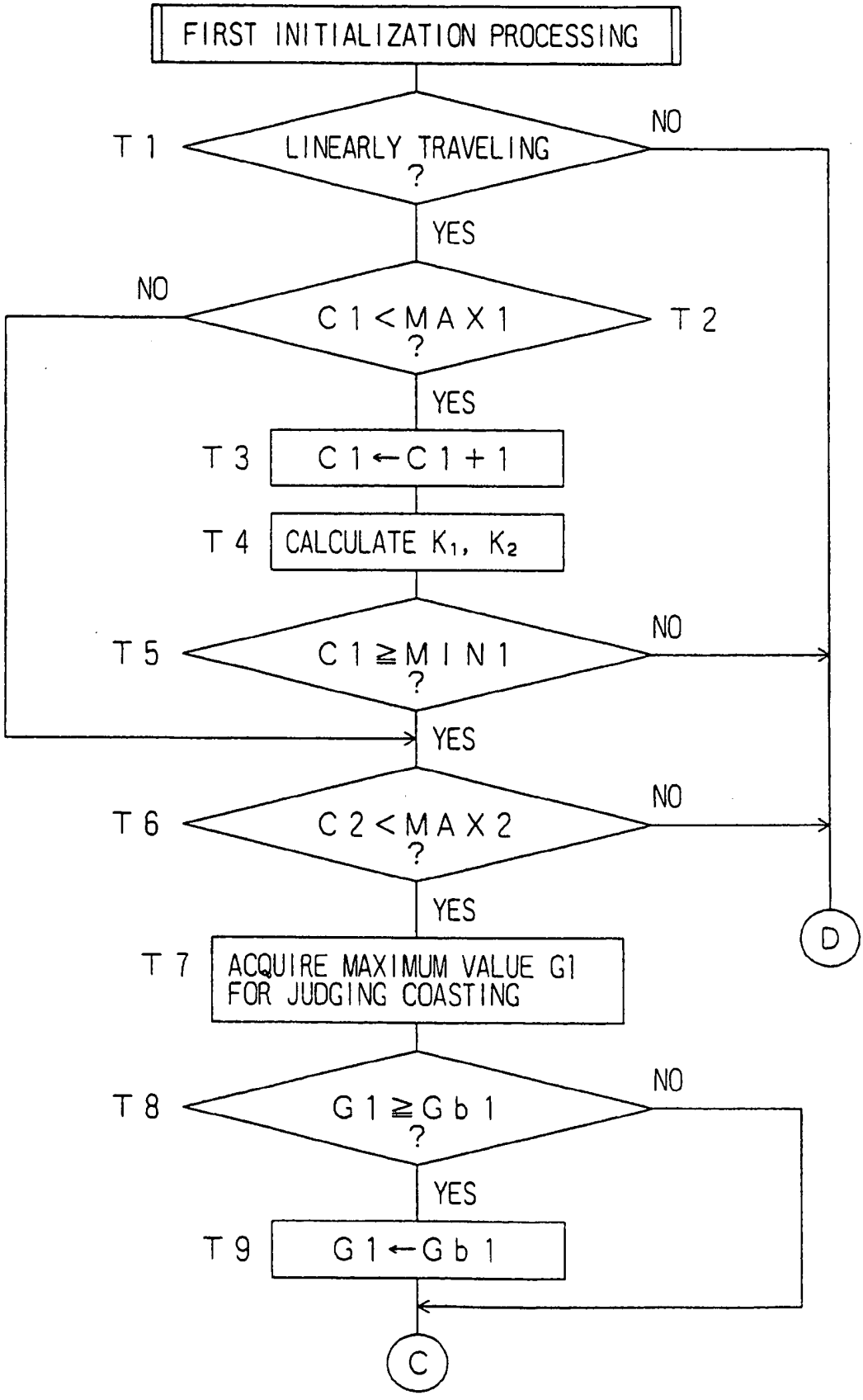

FIRST INITIALIZATION PROCESSING
T 1
LINEARLY TRAVELING ?
NO
YES
NO
C 1 < MAX 1 ?
T 2
YES
T 3
C 1 ← C 1 + 1
T 4
CALCULATE K1, K2
T 5
C 1 ≧ MIN 1 ?
NO
YES
T 6
C 2 < MAX 2 ?
NO
YES
D
T 7
ACQUIRE MAXIMUM VALUE G1 FOR JUDGING COASTING
T 8
G 1 ≧ Gb 1 ?
NO
YES
T 9
G 1 ← Gb 1
C

FIG. 6

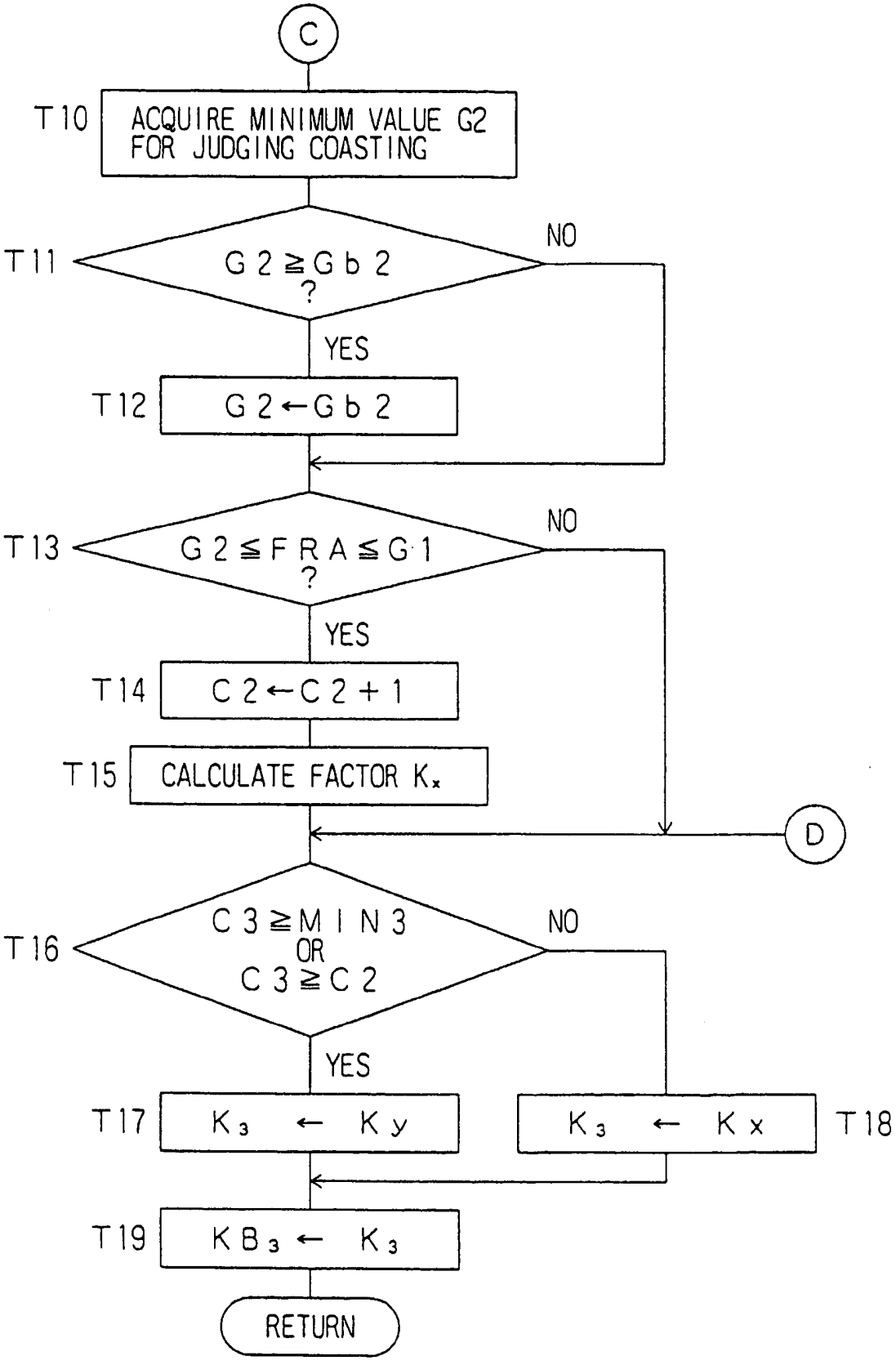

C
T10
ACQUIRE MINIMUM VALUE G2 FOR JUDGING COASTING
T11
G 2 ≧ G b 2 ?
NO
YES
T12
G 2 ← G b 2
T13
G 2 ≦ F R A ≦ G 1 ?
NO
YES
T14
C 2 ← C 2 + 1
T15
CALCULATE FACTOR Kx
D
T16
C 3 ≧ M I N 3 OR C 3 ≧ C 2
NO
YES
T17
K3 ← K y
K3 ← K x
T18
T19
KB3 ← K3
RETURN

FIG. 7

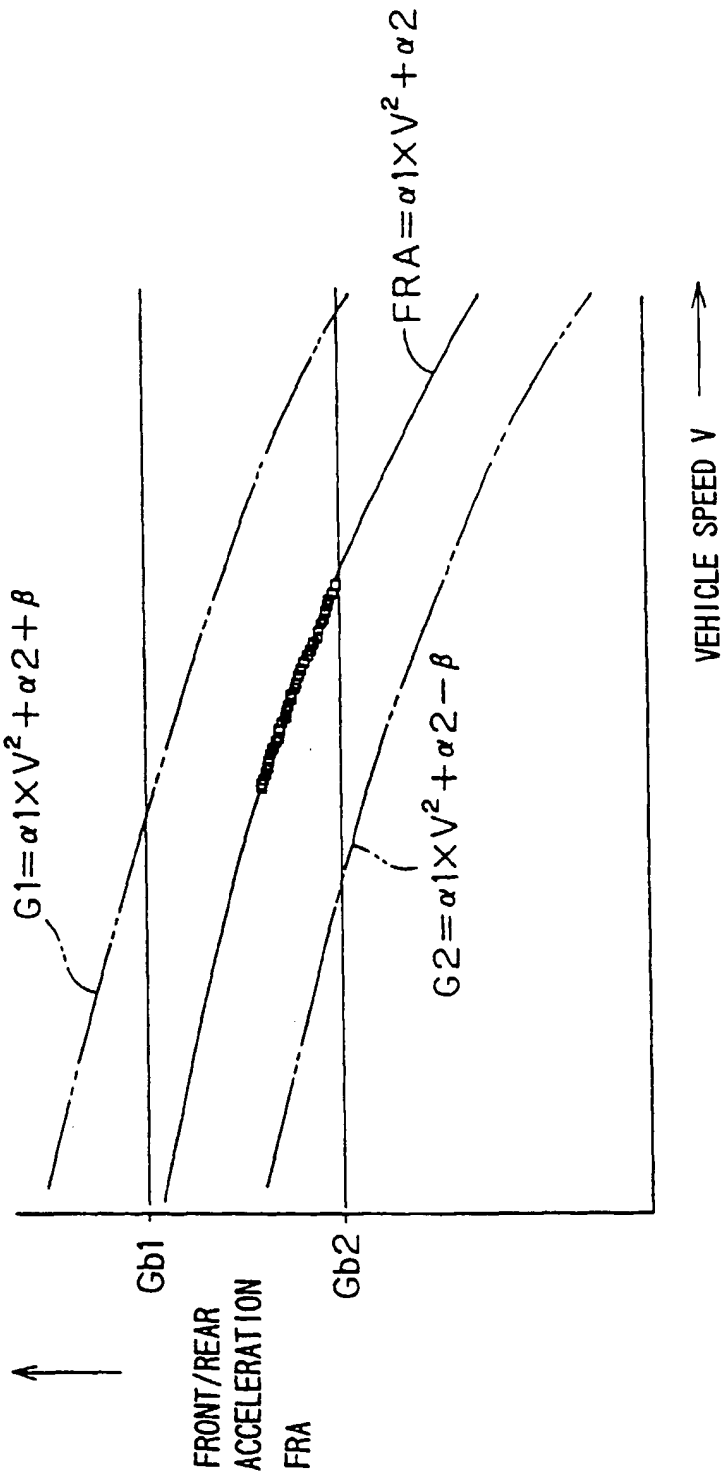
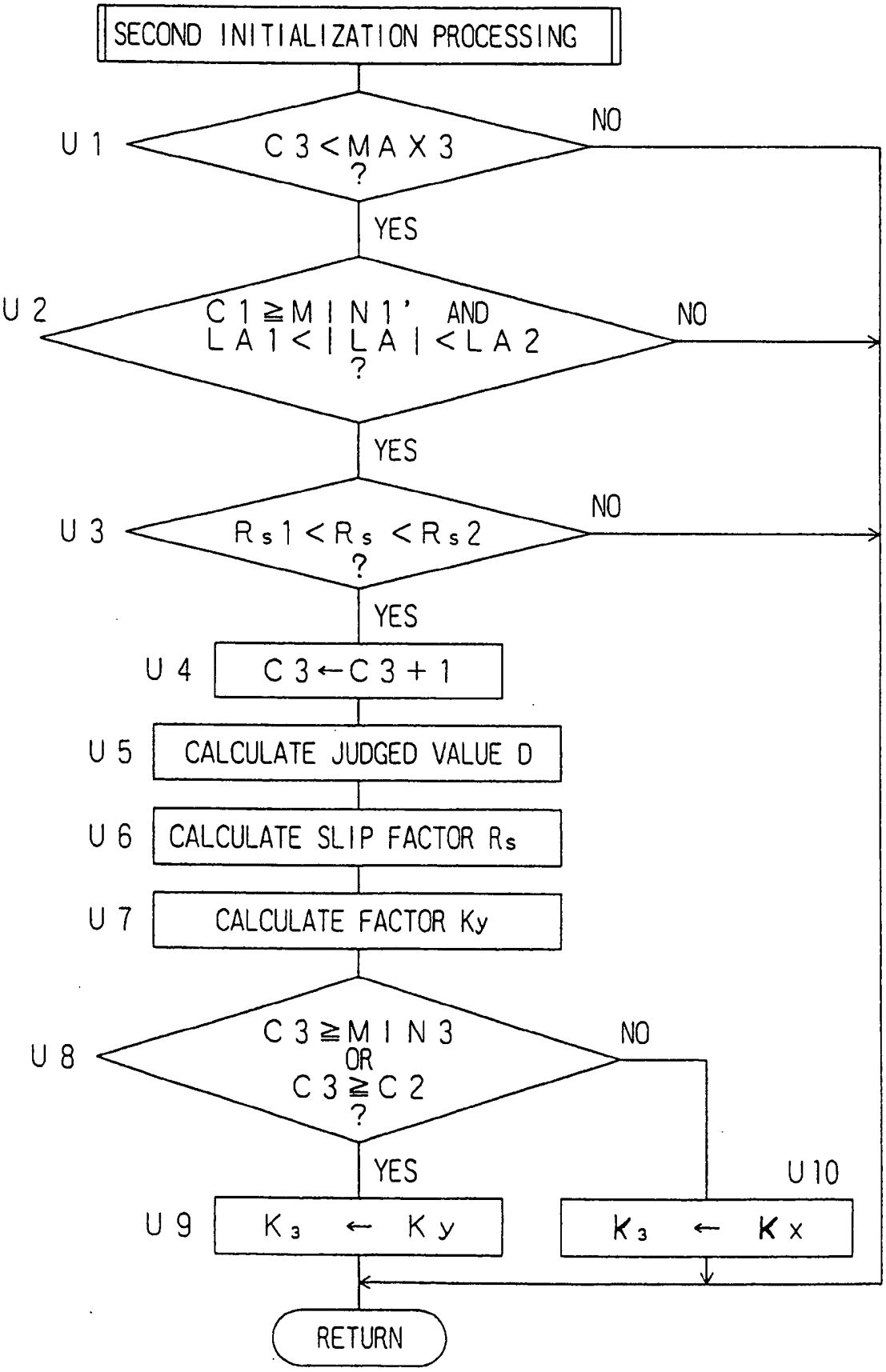

G1=α1×V²+α2+β
FRA=α1×V²+α2
G2=α1×V²+α2−β
Gb1
Gb2
FRONT/REAR ACCELERATION FRA
VEHICLE SPEED V

FIG. 8


SECOND INITIALIZATION PROCESSING
U1
C3<MAX3 ?
NO
YES
U2
C1≧MIN1' AND LA1<|LA|<LA2 ?
NO
YES
U3
Rs1<Rs<Rs2 ?
NO
YES
U4
C3←C3+1
U5
CALCULATE JUDGED VALUE D
U6
CALCULATE SLIP FACTOR Rs
U7
CALCULATE FACTOR Ky
U8
C3≧MIN3 OR C3≧C2 ?
NO
YES
U9
K3 ← Ky
U10
K3 ← Kx
RETURN

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 1381

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
E	EP 0 826 968 A (SUMITOMO RUBBER IND ;SUMITOMO ELECTRIC INDUSTRIES (JP)) 4 March 1998 * page 8, line 17 - page 8, column 33 * * page 14, line 25 - page 15, line 45; figure 7 *	1,2	G01P21/02 G01P3/56 G01P3/00 B60C23/06
X	EP 0 510 466 A (BOSCH GMBH ROBERT) 28 October 1992 * the whole document *	1,2	
A	MAYER H: "COMPARATIVE DIAGNOSIS OF TYRE PRESSURES" PROCEEDINGS OF THE CONFERENCE ON CONTROL APPLICATIONS, GLASGOW, AUG. 24 - 26, 1994, vol. VOL. 1, no. CONF. 3, 24 August 1994, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 627-632, XP000682538 * abstract *	1	
A	US 5 415 468 A (LATARNIK MICHAEL ET AL) 16 May 1995 * abstract *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6) G01P B60C
A	US 5 179 526 A (ZIMMER RICHARD ET AL) 12 January 1993 * abstract *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	5 May 1998	Felicetti, C

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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